THE NINTH

MARCEL GROSSMANN MEETING

On recent developments in theoretical and experimental general relativity, gravitation, and relativistic field theories

Proceedings of the MGIX MM Meeting held at
The University of Rome "La Sapienza"
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THE MARCEL GROSSMANN MEETINGS

The Marcel Grossmann Meetings were conceived with the aim of reviewing recent developments in gravitation and general relativity, with major emphasis on mathematical foundations and physical predictions. Their main objective is to bring together scientists from diverse backgrounds in order to deepen our understanding of spacetime structure and review the status of experiments testing Einstein's theory of gravitation.

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Group photo on the steps in front of the main meeting hall Aula Magna.

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MARCEL GROSSMANN AWARDS

NINTH MARCEL GROSSMANN MEETING

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THE SOLVAY INSTITUTES
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"for identifying and recording in discussions with the protagonists the crucial developments of physics and astrophysics in the twentieth century
—presented to Jacques Solvay

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Riccardo Giacconi

"for opening, five successive times, new highways for exploring the Universe"

Roger Penrose

"for extending the mathematical and geometrical grounds of general relativity"

Cecile and Bryce DeWitt

"for promoting general relativity and mathematics research and inventing the "summer school" concept"

Each recipient is presented with a silver casting of the TEST sculpture by the artist A. Pierelli. The original casting was presented to His Holiness Pope John Paul II on the first occasion of the Marcel Grossmann Awards.

FOURTH MARCEL GROSSMANN MEETING

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THE VATICAN OBSERVATORY

Individual Awards

WILLIAM FAIRBANK
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FIFTH MARCEL GROSSMANN MEETING

Institutional Award

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THE HUBBLE SPACE TELESCOPE INSTITUTE

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EIGHTH MARCEL GROSSMANN MEETING

Institutional Award

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Individual Awards

TULLIO REGGE
FRANCIS EVERITT

PREFACE

In 1975 the Marcel Grossmann Meetings were established by Remo Ruffini and Abdus Salam in order to provide a forum to meet every three years to discuss recent advances in gravitation, general relativity and relativistic field theories, emphasizing their mathematical foundations, physical predictions and experimental tests. These meetings aim to facilitate the exchange of ideas among scientists to deepen our understanding of space-time structures and to review the status of ongoing experiments and observations testing Einstein's theory of gravitation either from the ground or space.

The Marcel Grossmann Meetings have since grown under the guidance of an International Organizing Committee and a large International Coordinating Committee. The first two meetings MG1 and MG2 were held in Trieste (1975, 1979). A most memorable MG3 (1982) was held in Shanghai and was the first truly international scientific meeting that took place in China after the so-called cultural revolution. MG4 was held in Rome (1985). The topics presented at these meetings have gradually broadened in order to focus on issues of major scientific interest. It was in this way at MG4 that the birth of "astroparticle physics" was testified to in the inaugural lecture of Abdus Salam and by entire sessions dedicated to this new topic. These first four meetings were published by North Holland in Amsterdam.

Starting with MG5 held in Perth (1988), the proceedings have been published by World Scientific in Singapore. General relativistic theories have become more and more the theoretical foundation for a very broad new field of research encompassing experiments and observations which make use of techniques from space missions in the optical, X- and gamma-ray wavelengths as well as large radio and optical ground-based observatories all the way to underground laboratories. The enormous momentum gained following very large investments in observational techniques, unprecedented in other areas of science, has gradually led to the maturing of a new field of research: relativistic astrophysics. Paradoxically Einstein's theory born as a purely theoretical and mathematical conceptual revolution with extremely feeble supporting experimental evidence has become the driving force in the theoretical understanding of possibly the largest observational and experimental scientific effort in the history of mankind. The Marcel Grossmann meetings have followed these developments at MG6 (Kyoto, 1991), MG7 (Stanford, 1994) and MG8 (Jerusalem, 1997), becoming an important point of reference for this field.

MG9, or 'MG IX MM' to emphasize the millennium change, was organized by its International Organizing Committee composed of D.Blair, Y.Choquet-Bruhat, D.Christodoulou, T.Damour, J.Ehlers, F.Everitt, Fang Li Zhi, S.Hawking, Y.Ne'eman, R.Ruffini (chair), H.Sato, R.Sunyaev, and S.Weinberg. Essential to its planning was an International Coordinating Committee of 135 members from scientific institutions of 54 countries. In terms of the number of participants MGIXMM was the largest of the Marcel Grossmann Meetings, attended by 997 scientists of 69 nationalities.

Its opening was held on July 2, 2000 in the Aula Magna hall of the University of Rome "La Sapienza", one of the largest universities of Europe, where Tullio Levi Civita and Enrico Fermi were members of the Faculty of Science. Official addresses

included one by the President of the University. From then until July 8, the campus of the University designed in 1936 by a team of architects led by Marcello Piacentini, was the arena for the intense work of the meeting. The morning sessions included 34 plenary talks,while the parallel sessions, 88 in total, were held in the afternoons, both having review talks and original contributions.

Following tradition the Marcel Grossmann Award ceremonies were held during the meeting, this time taking place in the "Sala della Protomoteca" of the Campidoglio, the city hall of Rome. Individual awards were presented to Cecille and Bryce DeWitt, Riccardo Giacconi and Roger Penrose, while the Institutional Award went to the Solvay Institute, accepted on behalf of the Institute by Jacques Solvay and Ilya Prigogine. The award is given in the form of a silver replica of the sculpture TEST (Traction of Events in Space and Time) created by the Italian sculptor Attilio Pierelli.

The social program included tours around Rome, and the banquets were held in two beautiful palaces of old Rome, Palazzo Colonna (hosted by Prince Colonna) and Palazzo Lancellotti, in order to accommodate so many participants.

The meeting ended on July 8, 2000 at the closing ceremony in the Aula Magna.

Remo Ruffini thanked the members of the Organizing and Coordinating Committees for their continuing efforts and the Italian Ministery of Foreign Affairs, EC, IUPAP, UNESCO, ICTP for financial support which led to the success of a forum on such a scale.

The three volumes of the proceedings of MGIXMM present a rather authoritative view of relativistic astrophysics which is now becoming one of the priorities in the scientific endeavour. The first volume includes the plenary talks and parallel session review talks, while the last two volumes include the remaining contributions to the parallel sessions. The acceptance speeches for the Marcel Grossmann Awards are also included in these proceedings.

The papers that appear in these three volumes cover all aspects of gravitation, from mathematical issues to recent observations and experiments, summarizing a complete picture of our current understanding of gravitational theories at the turn of the millennium.

Inaugural Address

It gives me great pleasure this morning to participate in the inauguration of this Ninth Marcel Grossmann Meeting, symbolized by the Roman numerals MGIXMM, and organized by the International Center for Relativistic Astrophysics(ICRA) at the University of Rome"la Sapienza."

In fact we have been following these activities with treat interest since the establishment of the Grossmann Meetings in 1975 by the Nobel laureate Abdus Salam together with professor Remo Ruffini. We enthusiastically supported the goal of creating a close interaction between physicists and mathematicians at an international level to probe the consequences of Einstein's theory for a deeper understanding of our universe.

After the first two meetings, MG1 in 1975 and MG2 in 1979, both held in Trieste, Italy, the Third Marcel Grossmann Meeting MG3 took place in Shanghai, China in 1982. On that occasion we applauded the efforts made in close contact with the Italian Foreign Ministry, which finally led to the historical precedent-setting event of scientists from Israel, South Korea and the Vatican first entering China to attend an international meeting, even though China had no diplomatic relations with those countries. This remarkable result achieved for that meeting has continued to hold for subsequent international scientific meetings in China, clearly reaffirming the principle that scientific dialog should be kept open among scientists and held above any political, racial or religious barriers.

In 1985 the Fourth Marcel Grossmann Meeting MG4 returned to Italy and was held right here in Rome. It was on that occasion that ICRA was established linking "la Sapienza" to some of the leading institutions working in astrophysics, in China with the University of Science and Technology, in Europe with the Specola Vaticana and the ICTP and WAS in Trieste, and in the United States of America with Stanford University and the Space Telescope Institute.

This further step involved our university, which extends its roots into the remote past of some 1200 years ago and which has played a central role through various moments in the history of Italy. Just to mention a few examples in your field of interest, Gregorio Ricci-Curbastro and Tullio Levi-Civita were here in the school of mathematics establishing the basis for the mathematical fornulation of Einstein's theory of general relativity. Mario Orso Corbino was the founder of that very famous group of young scientists who under the leadership of Enrico Fermi unveiled to the world so many aspects of nuclear physics.

But in addition to these enormous successes there have been also tragic moments: "la Sapienza" was severely affected by the loss of some of its most distinguished faculty members because of the so called "racial laws."

Still, it was on this campus that a positive sign of reconstruction was given by a group of young physicists who started a new branch of physics research just at the end of the Second World War: the study of elementary particle physics. A unique role was played by Edoardo Amaldi for his fundamental role in the creation of the National Laboratories at Frascati, in creating the Istituto Nazionale di Fisica Nucleare (INFN) and for his promotion, under the aegis of UNESCO, of the European Center for Nuclear Research (CERN) in Geneva.

All of this scientific structure has offered opportunities to scientists from all over the world and to a new class of Italian scientists who have achieved respect and scientific success for Italy.

Turning our attention back to ICRA, in addition to its many scientific activities in the young field of relativistic astrophsics, it has also been guiding the further developments of the Marcel Grossmann Meetings all over the world with the support of the Italian embassies in many countries.

In 1988, MG5 was held in Australia in the beautiful town of Perth at the celebrated campus of the University of Western Australia on the Swan River. In 1991, MG6 was held in Japan in the historical town of Kyoto close to the school of the Nobel Laureate Yideki Yukawa. In 1994, MG7 was held in the United States of America at the Stanford University campus at the very heart of Silicon Valley, and finally in 1997, MG8 was held in Jerusalem at the Hebrew University on the hills of the Holy City where all the manuscripts of Albert Einstein are kept as a treasure for humanity.

Also the present meeting returning to Rome is marked by a new activity also promoted by "la Sapienza": the ICRA Network which will be coordinated by the Center for Astrophysics in Pescara. We are especially thankful to the Mayor of Pescara, Carlo Pace, for his contribution in making this project a reality.

Using the new electronic highway of communication among scientific institutions, the ICRA Network will coordinate the scientific work in theoretical astrophysics among leading centers of research in the Americas, Australia, China, France, Italy, Russia, the Vatican and finally Vietnam (on behalf of the ten Southeast Asian ASPAN countries.

The fact that a thousand scientists from sixty-three different nations are convened here today to discuss the understanding of our universe at the beginning of the new millennium encourages us to expect that this new initiative of "la Sapienza", the ICRA Network, will also be as successful as the previous ones.

I would like to close my remarks with the motto that was forged by the founders of the Grossmann Meetings "In understanding the laws of nature, no country can afford the luxury of having another country think for it." Our university fully supports this philosophy.

I extend to all of you my warm personal wishes for a successful and enjoyable scientific week in Rome.

Giuseppe D'Ascenzo
Rector of "la Sapienza"
University of Rome

Riccardo Giacconi

Roger Penrose and Francis Everitt

Cecile DeWitt-Morette and Bryce DeWitt

Marcel Grossmann Award Talk

Cecile DeWitt-Morette
Department of Physics, University of Texas at Austin, Austin, TX 78712 USA

Thank you for a prestigious—and most unexpected award. A prize awarded jointly with Bryce is an exceptional event. As a matter of fact, this is the second time a physics community presents us jointly with a gift. The first time was in 1951 at the end of the first Les Houches session. All through the summer I had discreetly hidden the symptoms of my first pregnancy, but Daniel Kastler, sure of his diagnostic, had talked to the participants, and on the last evening Bryce and I were presented with a collapsible baby bed, perfect for travelling. Our four daughters have used it.

As colleagues we have only 3 joint papers. The baby bed was more a trust for the future than a reward for the early beginning. I think of the Grossmann award as a trust for the future. We owe you at least a fourth joint paper. Let us face it we look at physics problems differently. But I am aware that if we could bring together our different insights, our different ways, the outcome would benefit.

Thank you for your trust in the joint work to come.

Enough about us. Some comments about Summer Schools.

Les Houches was well summarized by Leon Rosenfeld: "J'y ai trouvé la paix nécessaire à un travail intellectuel intense et la stimulation d'un auditoire d' élite". (I found there a quiet place necessary for intense intellectual work together with the stimulation of an elite audience.) In 1950 I was acutely aware of the need of a pedagogical summer school. Fifty years later I am acutely aware of another need. We have to cope with stress; we sail in fast currents, we need quiet harbors to careen our boats, to recalk, and to refill our water barrels. Les Houches is now comfortable. I hope that shortly Les Houches will offer a few places, without obligations, to physicists in need of quiet for several weeks. Remo, to thank you for the amazing Marcel Grossmann meetings I would like to offer you several quiet weeks at Les Houches.

Ilya Prigogine, Remo Ruffini and Jacques Solvay

Marcel Grossmann Award Talk

Jacques Solvay
Brussels, Belgium

Ladies and Gentlemen, Authorities,

Dear Professor Ruffini,

I want first to express my gratitude for the presentation of the "Marcel Grossmann Award" to the Internatonal Solvay Institutes, founded by Ernest Solvay. I am also very happy to be here especially in this historical place.

May I first tell you an anecdote? Emest Solvay, my great-grandfather, was a man of multiple interests. He was equally attracted by physics, chemistry, physiology and sociology. He was in regular correspondence with outstanding people of his time such as Nernst and Ostwald. This was a period where difficulties had appeared in the interpretation of specific heat by classical physics. Ernst Solvay was bold enough to have his own opinion on this subject. He thought there were surface tension effects and he expressed his view in a meeting with Nernst in 1910. Nernst was a practical man. He immediately suggested that Ernest Solvay should organise an international meeting to present his point of view. This was the starting point for the Solvay Conferences, the first of which took place in 1911. The Chairman was the famous physicist H.A. Lorentz.

At the end of the conference, Lorentz thanked Ernest Solvay not only for his hospitality but also for his scientific contribution. However, in fact his contribution was not even discussed during the meeting. Ernest Solvay was not too disappointed. He thought he had just to continue to work and he appreciated greatly the first conference dealing with radiation theory and quanta. He therefore decided to organise the "Solvay Institute in Physics" which was founded in May 1912. He called it the "Institut International de Physique" with the goal "to encourage research which would extend and deepen the knowledge of natural phenomena."

The new foundation was intended to concentrate on the "progress of physics". Article 10 of the statutes required that "at times determined by the Scientific Committec a 'Conseil de Physique,' analogous to the one convened by Ernest Solvay in October 1911, will gather, having for its goal the examination of significant problems of physics." A little later, Ernest Solvay established another foundation "Institut International de Chimic." The two foundations were ultirnately united into "Les Instituts Internationaux de Physique et de Chimie," each one having its own Scientific Committee.

The first Solvay Conferenee on Physics had set the style for a new type of scientific meetings, in which a select group of the most well informed experts in a given field would meet to discuss the problems at the frontiers, and would seek to identify the steps for their solution. But for the interruptions due to the two World Wars, these international conferences on physics have taken place almost regularly since 1911 mostly in Brussels. They have been unique occasions for physicists to discuss the fundamental problems which were at the center of interest at different periods and have stimulated the development of physical science in many ways. This was a time where international meetings were very exceptional.

The Solvay Conferences have been unexpectedly successful. In his foreword to the book by Jadgish Mehra *The Solvay Conferences on Physcs*, Heisenberg wrote

"I have taken up these remnscences in this foreword in order to emphasise that the historcal influence of the Solvay Conferences on the development of physics was connected wth the special style introduced by their founder. The Solvay Meetings have stood as an example of how much well-planned and well-organised conferences can contribute to the progress of scence."

It was often said that the people who met at Solvay Conferences went on to Stockholm to receive the Nobel Prize. This is a little exaggerated but there is some truth in it. It is also at the Solvay Conference in 1930 that one of the most famous discussions in the history of modern science took place. This was the discussion between Einstein and Bohr on the foundations of quantum theory. Nearly 70 years later it is remarkable to notice that physicists seem not to agree who won.

There is another more personal aspect that influenced the development of the Solvay Conferences. When my friend Ilya Prigogine some 40 years ago in 1958 was appointed Director of the Institutes, he extended their activities from organizing conferences to doing research especially in thermodynancs and the relation between dynamics and broken time symmetry.

Since the Institutes evolved into a mini Institute for Advanced Study. In that role, they were an impressive success. Work done within the Institutes has shown that far from equilibrium matter acquires new properties that form the basis of a new coherence.

The present research activities of the Solvay Institutes cover both fundamental and applied problems. The fundamental aspect of this activity is focused on the probabilistic description of different classes of unstable or non-integrable systems and including the dynamic foundation of thermo-dynamic systems. These new probabilistic extensions required new mathematical tools.

We all know Professor Prigogine's passion for the understanding of time. The flow of time is present at various levels of observation be it cosmology, thermodynamics, biology or economics. Moreover time is the basic existential dimension of man and nobody can remain indifferent to the problem of time. We all care for the future, especially in the transition period in which we live today.

This is a great mornent for the International Solvay Institutes. It is remarkable that this institute which was founded about 90 years ago has kept its international reputation. The "Marcel Grossman Award" is the best proof. In addition, this gives me an opportunity to come to Rome which, as everybody knows, is the fountain of Western culture.

Marcel Grossmann Award Talk

Ilya Prigogine
Brussels, Belgium

Ladies and Gentlemen, Dear Friends,

I regret that I cannot make my speech in Italian. Even more as I always had the greatest admiration for Italian creativity both in sciences and the arts. So I shall use the international scientific language, broken English.

Mr. Solvay bas already expressed our gratitude to the Marcel Grossman scientific committee, and especially to Prof. Ruffini, for giving the Marcel Grossmann prize to tbe Solvay Institutes for its contributions to relativity.

There have been three Solvay mectings devoted to cosmology and gravitation, in 1958, 1964 and 1973 in which, of course, relativity played a fundamental role. Prof. Ruffini was present in the 1973 symposium. It was a great period as there were still controversies between the steady state theory and the evolutionary view starting with the Big Bang. At the meeting in 1958 Lemaitre was suggesting that we could observe remnants following what he called the primeval atom. This suggestion led finally to the prediction of a residual black body radiation. As Mr. Solvay mentioned, I tried to turn the Solvay Institutes into a mini Advanced Institute. In this perspective there was always work on relativity. The Solvay Institutes has sponsored the general relativity centre at the University of Brussels directed by Professor Edgard Gunzig.

I have been interested since a long time in the relation between relativity and the problem of time as analysed by Einstein. However, his analysis seems not complete because it does not contain the notion of the arrow of time which plays an essential role in the world around us. From the microscopic point of view, we know now that nonequilibrium leads to new structures. This is the best proof that the arrow of time plays an important role. But it is a microscopic pieture. What is essential is how does this picture as we know it relate to the eigenvalue problem of the Liouville operator. We have now a remarkably simple answer. The Liouville operator is an hermistic operator. In Hilbert space it has only real eigenvalues. The evolution of probability is a solution of the Liouville operator. Therefore, the problem of irreversibility forces us to go to more general function spaces.

Probabilitics may be reducible to wave functions or trajectories or irreducible in extended functional spaces. The first example was the discovery of new representation outside the Hilbert space for the Baker transformations. But the most important example concerns thermodynamical assistance in which there is a finite concentration and when the wave energy is proportional to the volume. With thermodynamics we have shown that these simple conditions cannot be satisfied in Hilbert space. The system is kicked out from the Hilbert Space as in the examples studied by Dirac. This then leads to unification of dynamics and thermodynamics. But we still don't know what happens once we consider the problem in general relativity which remains unsolved.

In these studies we met surprises. One of them is the fact pointed out by Hegerfeldt that the positivity of energy in quantum mechanics leads to the con-

clusion that any localized state immediately after the initial moment has a nonvanishing influence at arbitrary distance. In other words, any quantum system with positive energy being initially localised in a finite region develops infinite tails immediately after. This touches the problem of superluminal propagation which has been widely discussed over the last decade. Various authors have claimed the observation of superluminal signal propagation. We have been led to a different interpretation. We considered first free relativistic fields. As a special case, we considered classical solutions of the Klein-Gordon equation and quantum boson fields. We demonstrated that the localised objects, which are formed by positive frequency only are superpositions of two complex nonlocal objects propagating with the speed of light. In the initial moment a destructive interference cancels the nonlocal taiis. However, this cancellation holds only one instant and infinite tails appear immediately after.

This effect is a kind of "curtain effect" due to the nonlocality of the structures present. Nonlocality arising in systems with positive energy has also an influence on particle dressing. For example, a bare particle, which is a localized object, gets dressed when it is coupled with the radiation field. The dressing is a cloud of photons sticking around the particle. This cloud is nonlocai and appears instantancously exactly as the infinite tails in our free field example.

For stable particles this dressing is known. However, till now there was no satisfactory deseription of unstable particles as the usual theory leads to the elimination of the particle (see Friedrichs model). To construct an object describing the unstable particle we need to work with irreducibie density matrixes in the Liouville space. The unstable particle is associated with a nonfactorizabie extension of the density matrix. Due to positivity of energy there exists again a "curtain effect". If we choose as the initial condition, the bare excited state, which is localized, the field modes cancel each other by destructive interference. Then one part of the nonlocal photons, which we call Zeno photons, is going away with the velocity of light. Ali this is described in articles to appear soon in *Physical Review*. Another part of the photon cloud is staying around the paiticle. This is precisely the dressing. In this way, the cancellation is destroyed and there is nonvanishing probability to find a photon at any space point. The space distribution of the dressing photons has a maximum at the place of the bare particle and decays with a power law in space. Once the Zeno photons leave the particle is dressed. The escape of the Zeno photon leads to the well known deviation of the time dependence of probabilit from the exponential law for short times. We intend to extend this description to interacting fields. Quantum transitions are more complicated, more complex than considered till now.

Another aspect of the concept of time is that there is no operator corresponding to time in quantum mechanics. Already twenty years ago, Professor Misra introduced a time superoperator in Liouville space which leads to an uncertainty relation quite similar to Heisenberg's uncertainty relations. However, this concept has been explored more extensively only in the last years. the time operator introduces the idea of fluctuations of age.

An example may be usefui. Brasilia was built at a well defined time. Rome is a mixture of buildings corresponding to different periods. In this view, Brasilia

has a very defined eigenvalue and eigenfunction of the time superoperator while Rome would be a superposition and leading to an average time and probability distribution of ages.

According to Plato, change in time was the starting point of philosophy. It still remains a fascinating subject. We only begin to understand the origin of the complexity around us. Partly as a result of non-equilibrium time has many faces which we begin to explore. We are highly encouraged in our research by the Marcel Grossmann award. Again, I thank you all very much.